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Design Criteria and Energy Savings Report

Analysis of Outdoor Lighting Baseline Assessment (PIER) and Outdoor Lighting Research (Eley Associates) reports

Report by Lawrence Berkeley National Laboratory

Executive Summary

This analysis is part of a larger project to suggest appropriate retrofit strategies and code recommendations for lighting of parking lots in California. The report examines two recent documents relating to outdoor lighting standards: the *Outdoor Lighting Baseline Assessment* (PIER, November 11, 2002) and *Outdoor Lighting Research* (Eley Associates, June 6, 2002). The PIER report provides baseline information that is used to estimate the potential energy savings from retrofit strategies and changes to the energy code. The Eley report proposes draft standards for outdoor lighting. In this analysis, we evaluate the three main energy saving strategies proposed in these documents for parking lot lighting: 1) light source efficacy improvements and lamp replacements; 2) reduced power densities; and 3) application of lighting controls (curfews). The following are our most important findings with regard to these proposed strategies:

- **The energy savings from improved light source efficacy may not be as large as expected.** Because there are large differences in efficacy between the various light sources that are currently used in parking lots, this represents a potential avenue for future energy savings. However, the information available in the PIER report suggests that existing parking lot lighting that uses inefficient sources has lower power densities and illumination levels than lots with more efficient sources. Incandescent and halogen lamps (the most inefficient sources) constitute almost 10 percent of installed sources, but represent only about 6 percent of the total energy used in parking lots. This suggests that replacement of these sources may only save a small fraction of this energy use.

- **The energy savings from lamp replacement strategies may also not be as large as expected.** The PIER report proposes a theoretical scenario where all existing high pressure sodium lamps (HPS) are replaced with metal halide (MH) lamps, and estimates a potential savings of 33 percent from this strategy. This estimate is based on the hypothesis that less power is required to achieve equal brightness lumens from MH lamps as compared to HPS lamps. However, as there is a large efficacy versus wattage effect, an estimate of 10-15 percent savings may be more appropriate. In addition, there are theoretical questions that remain to be answered with regard to whether Berman's brightness measure is valid for use in parking lots. If this measure is not valid, replacing HPS lamps with MH lamps would still achieve energy savings, but at the expense of visual performance.

- **It may be difficult to meet both the power density requirements and the illuminance criteria if installations differ from the standard layout.** The power density requirements proposed in the draft standard are based on illuminance criteria established by the IESNA in its recommendations for parking lot lighting (RP-20-98). The Eley report establishes a standard grid for calculating both the power densities and the illuminance requirements. Actual parking lot installations are likely to vary from this standard layout, and may not be able to meet the illuminance criteria under the specified power densities. In addition, there may have been an error in calculating the minimum illuminance in the Eley report. If adequate illumination (especially for safety reasons) is a significant concern, these possible discrepancies should be considered more carefully as changes are made to the lighting code.

- **Curfew switching may not be feasible due to the limitations of current technology and also to safety concerns.** The Eley report proposes a 50 percent reduction in power after curfew for Lighting Zones 2 through 4, and a 90 percent reduction for Lighting Zone 1 (LZ1). It may be difficult to meet these reduced power requirements without compromising the illumination levels required for safety purposes. The especially low light levels required in LZ1 may not be sufficient to prevent transient blindness in pedestrians in the face of automobile headlights.

Based on this analysis, we recommend the following additional or alternative strategies for energy savings:

- **Establish a set of optimal candlepower distributions for a range of layouts.** In order to meet both the power density requirements and the recommended illuminance criteria, a reasonably good control of the illuminance uniformity is required. As actual parking lots will vary in their size and shape, the candlepower distribution from a particular luminaire may not be ideal for all situations. The best approach is to define the most common layouts for parking lots and then specify a set of candlepower distributions that work best over a range of conditions for these layouts.

- **Develop retrofit post-top fixtures based on optimal candlepower specifications.** This represents the most promising opportunity to develop energy-efficient new and retrofit fixtures for existing parking lots.

- **Also consider wall mount fixtures as a potential target for retrofit efforts.** Much of the ongoing discussion regarding retrofit fixtures for parking lot lighting has centered on pole- or post-top fixtures. The PIER report indicates that over one-third of existing parking lot fixtures can be classified under the category of "wall-mount." As wall mount fixtures often do not have any glare control, this category has the greatest potential for glare reduction. These are also the least efficient type of fixtures. Wall-mounted fixtures light the lot from only one side, which makes it more difficult to obtain good uniformity, and hence good energy efficiency. Both of these problems may be addressable by changes in optical design that lead to a more optimal candlepower distribution for typical parking lot geometries. Additionally, reducing glare leads to reduced light trespass and light pollution, and enhances visibility within the space.

- **Use motion detectors instead of curfews.** As it may not be feasible or desirable to reduce lighting power to the proposed curfew levels, using motion detectors is a possible strategy to consider. It might be argued that it is the *potential* for demand, and not actual demand, that is low during curfew periods. A motion detector would allow the installed lighting to provide full illumination when it is required and to turn down the lights when there is no activity.

- **Continue (at present) to allow use of both HPS and MH lamps**. Because it is not clear whether the brightness lumen hypothesis referenced in the PIER report is valid for parking lots, it is not appropriate at this time to mandate a replacement of HPS lamps with MH lamps. For most visual tasks that depend upon photopic luminance, previous research has shown that HPS lamps are superior to MH lamps at equal wattages. This suggests that MH lighting may not provide equal performance if HPS lamps are replaced with lower-wattage MH lamps.

Introduction

This analysis is part of a larger project to suggest appropriate retrofit strategies and code recommendations for lighting of outdoor parking lots in California. The report examines two recent research documents relating to outdoor lighting standards: the *Outdoor Lighting Baseline Assessment* (PIER, November 11, 2002) and *Outdoor Lighting Research* (Eley Associates, June 6, 2002). These documents are the basis for the draft standards proposed by the CEC in June 2002. This report evaluates the major elements of each document and their implications for retrofit strategies and code changes. Recommendations for additional or alternative energy savings approaches are made based on this analysis.

Background

Outdoor Lighting Baseline Assessment (PIER)
The PIER report provides baseline information on current outdoor lighting use in California. This information is used to estimate the energy savings that could be achieved through retrofit strategies and changes to the energy code. The report includes tables to show the effect of switching from High Pressure Sodium (HPS) or Mercury (Hg) lighting to Metal Halide (MH) lighting using fixed efficiency ratio factors. It also shows the percentage of area in various power density ranges, so the user can evaluate the potential impact of different power density standards. The PIER report is a summary of more detailed information contained in an electronic database. This review only covers the written report, and not the underlying database.

Validity check
The PIER report estimates commercial outdoor lighting use (not including off-premise billboards) to be approximately 3,070 GWH/year. Parking lot lighting is the largest single use, at 31.5 percent (970 GWH) of the total. The written report does not provide explicit validation checks on these estimates. However, it does list an estimated power density of 0.08 watts/ft^2 (0.87 watts/m^2), and provides a load curve, which indicates that use is approximately 12 hours/day. This leads to a calculated parking lot area of 2.8 billion ft^2. The area per parking lot stall is 130 to 150 ft^2, but access and landscaping inflate the overall parking area to the range of 250 to 500 ft^2. A mid-range estimate of 360 gross ft^2/stall gives an estimate of 7.7 million outdoor parking stalls in the state, which is a reasonable value. This provides a validation check on the original energy use estimate.

Outdoor Lighting Research (Eley Associates)
The Eley report proposes draft standards for outdoor lighting in California. For parking lots, the standards have four key requirements: 1) maximum allowable power based on the environmental zone, 2) power reduction capabilities for night curfew, 3) efficacy standards for the lamps, and 4) a cut-off requirement for the fixtures. The power requirements are based on the design criteria established by the IESNA recommended practice for parking lots (RP-20-98). The report includes calculations (using metal halide

fixtures) to show that it is possible to meet both the power requirements of the draft standard and the IESNA illuminance criteria.

Discussion

The PIER and Eley reports address energy savings in parking lots through three main strategies: 1) improved light source efficacy, 2) reduced power levels, and 3) application of lighting controls. Both reports also briefly discuss the need for better glare control in parking lot fixtures. This section describes the specific recommendations made in the two reports and evaluates their energy savings potential. The key content is as follows:

1) Light source efficacy improvements
   a) Savings from increased efficacy standards
   b) Savings from replacement of mercury vapor lamps
   c) Savings from replacement of high pressure sodium lamps
   d) Impact of standards on other lamp types
2) Power and light levels
   a) Maximum power requirements for California environmental lighting zones
   b) Comparison of existing power densities and lighting zone designations
   c) Feasibility of meeting illuminance requirements under specified power densities
3) Proposed curfew requirements and potential implications
4) Glare, light pollution, and light trespass issues

Light sources
The PIER study found that all the major light sources are used in parking lots (Table 1). Because there are large differences in efficacy between these sources, this represents a potential avenue for future savings in both new and existing installations. As a means to achieve these savings, the Eley report proposes an efficacy standard of at least 60 lumens/watt for all lamps above 100W. Additionally, the PIER study evaluates the theoretical impact of replacing all mercury vapor (Hg) and high pressure sodium (HPS) lamps with metal halide (MH) lamps. The implications of these changes, including potential energy savings achieved, are discussed in the following sections.

Potential savings from increased efficacy standards
Increased efficacy standards are an appropriate strategy to eliminate the use of highly inefficient light sources (such as incandescent and halogen lamps). However, examination of the energy use profiles (power x hours use) for the various lamp types currently in use indicates that replacement of inefficient sources may not result in the expected level of energy savings. In Table 1 below, column 2 lists the percentage of area in parking lots that currently is lit by various types of lamps (from Table 44 in PIER report). Although the PIER report does not list the energy use by lamp type, it does give a savings estimate for converting HPS and Hg lamps to MH lamps at fixed wattage ratios. This information is used to calculate the absolute and percent energy use for these two lamps (columns 3 and 4 in Table 1). It can be seen from the table that although HPS lamps are among the most efficient sources available, their energy use fraction (30.1 percent) is higher than their fractional installed base (26.8 percent). This implies that the

installed HPS sources are either large-wattage lamps or they are operated for longer periods of time than other lamp types. The opposite is true for Hg lamps, which are relatively inefficient.

Table 1: Percent of total parking area using various lamp types

Lamp type	Percent area	KWH	Percent KWH
MH	37.8%		
HPS	26.8%	2.91E+08	30.1%
CFL	8.9%		
Hg	7.2%	6.35E+07	6.6%
Fluorescent	6.7%		
Incandescent	6.6%		
Halogen	3.1%		
LPS	2.9%		

With efficacies of less than 20 lumens/watt, many incandescent and halogen lamps will cease to be legal for new construction or remodel. The written PIER report does not give a wattage breakdown, so the electronic database will have to be examined to determine the fraction of these lamps that will be affected by the standard. The U.S. Lighting Market Characterization 2002 report estimates the average wattage of incandescent lamps as being only half that of HID sources. This is consistent with the trend seen in Table 1, where the more efficient HPS lamps have a wattage or use that is higher than average and the less efficient Hg lamps have a wattage or use that is lower than average. If the wattages for incandescent and lamps (9.7 percent of all lamps) is only about half that of HID lamps, then calculation suggests that their energy use will be approximately 6 percent of the total. Thus, replacing incandescent lamps with lamps of 60 lumens/watt (fluorescents or 50 watt or greater HPS) could save about 4 percent of current parking lot energy use, but only if there is a direct lumen replacement. The actual amount saved will depend on whether lots lit with incandescent lighting meet current lighting level recommendations and would continue to be lit at the same level, or whether they would need to be upgraded. Information on light level by lamp type will need to be determined from the database, as it is not in the written report.

Potential savings from replacement of mercury vapor lamps

The PIER report estimates that eventual replacement of Hg vapor lamps (7.2 percent of installed lamps) with MH lamps will save 24 GWH, or 2.5 percent of the current energy use for parking lots. The report estimates the energy saving per lamp by applying an efficacy ratio of 56/90 (0.62) for Hg to MH lamps. Below, Table 2 compares catalog data (Philips) for Hg and MH lamps. The values used in column 2 of the table are for phosphor coated Hg lamps, which are generally more efficient than clear lamps. Although the table does not include ballast losses, Hg lamps can be assumed to run on magnetic ballasts, which will have higher relative losses than the new ballasts that are now available for MH lamps.

Table 2: Hg and MH lamp efficacies

Hg lamp watts	Mean efficacy	MH lamp watts	Mean efficacy	Efficacy ratio
50	25.2	50	44.0	0.57
75	30.0	70	51.4	0.58
100	34.0	100	59.0	0.58
175	43.4	175	80.0	0.54
250	42.8	250	80.0	0.54
400	47.8	400	88.0	0.54
700	48.0	700	62.4	0.77
1000	47.5	1000	71.5	0.66

The actual energy savings achieved by replacing Hg lamps with MH lamps will depend upon whether fixture placement is retained, and whether the design light level is retained or changed. If the light level is unchanged, smaller MH lamps will replace the current Hg lamps. Table 3 below shows the wattage ratio between the Hg and MH lamps, for approximately equal lumen lamps. For the smaller lamps, the ratios are generally larger than those listed in the PIER report, but the tabulated values do not include ballast losses. If ballast losses are included, the ratios should be very similar to the PIER report estimate.

Table 3: Lamp wattage ratios for approximately equal lumen lamps

Hg watts	Mean lumens	MH watts	Mean lumens	Watts ratio
50	1260			
75	2250	50	2200	0.67
100	3400	70	3600	0.70
175	7600	100	5900	0.57
175	7600	125	8400	0.71
250	10700	150	10500	0.60
400	19100	250	20000	0.63
700	33600	400	35200	0.57
1000	47500	750	46800	0.75

As noted above, the actual energy savings from switching from Hg to MH will depend upon whether the light levels remain unchanged. While the written PIER report does not list light levels as a function of lamp type, it does provide information on the fraction of all lots with light levels in a set of ranges. Although these ranges do not line up precisely with the IESNA recommended levels for parking lots, they can be used to estimate the appropriate fractions. Currently, about 40 percent of existing lots do not meet the "basic" parking lot level (2 lux) recommended by the IESNA. It is likely that lots currently using an outdated light source (Hg lamps) are the ones that are most likely to be substandard in design. Table 1 shows that fewer lots use Hg lamps (plus incandescent lamps) than are substandard, so it is possible that all of the lots lit by Hg lamps are lit to substandard levels. If the light levels in these lots are increased, the resulting increase in energy use would counteract any potential savings achieved through lamp replacement. This suggests that much of the estimated energy savings will come from reductions in growth of energy use rather than reductions in current use.

Potential savings from replacement of high pressure sodium lamps
The PIER estimate of energy savings from switching from HPS to MH is 96 GWH, or 10 percent of current parking lot energy usage. This estimate is based on a power reduction of 33 percent to achieve equal brightness lumens. The brightness lumen is calculated as the photopic lumen times the square-root of the scotopic/photopic (S/P) ratio[1]. The S/P ratio depends upon the spectral power distribution of the lamp, and to a lesser extent, the spectral reflectance of the scene. Berman's 1992 paper[2] reported the following S/P ratio for lamps:

Table 4: S/P ratio for common lamps from Berman et. al., 1992

Lamp type	Min S/P	Max S/P
MH	1.49	2.1
HPS	0.4	0.62
Hg	0.8	
Fluorescent	1.0	2.22
Incandescent	1.41	
LPS	0.23	

This table just represents a sample of lamps, not all of which are common or current. There is a possibility of substantial variability in S/P ratios even within such seeming fairly simple categories as Hg lamps. For example, the Hg lamp in the table had very little energy in the deep blue at 410 and 440 nm, and more energy at 580 nm than at 550 nm. In contrast, the spectral power distributions for two generic Hg lamps (given in the IESNA handbook) show significant power in the deep blue and near the photopic peak at 550 nm, with S/P ratios of 1.4 to 1.47. These values are close to the value listed for modern MH lamps of moderate (4000° K) color temperature (1.5 to 1.7). The generic Hg lamps have almost the same S/P ratio as the MH reference lamp (1.5), so there is essentially no difference in energy savings calculated in terms of equal photopic lumens, or equal brightness lumens. This would not be true of the older Hg lamp used in the table. Thus, if brightness lumens are used as a basis for lamp replacement, there may be cases where actual energy savings would be larger than stated in the PIER report.

Tables 5 and 6 below show the ratio of efficacies for HPS and MH lamps in terms of both photopic and brightness lumens, assuming standard values of S/P = 1.5 for MH, and 0.6 for HPS. In Table 5, the comparison is given for equal wattages. In Table 6, the comparison is for lamps of approximately equal brightness lumen output.

The comparison in Table 5 is the same comparison used in the PIER report, where it was assumed that three HPS lamps are replaced by two MH lamps of equal wattage. This scenario gives equal brightness lumens if the efficacy ratio of HPS/MH is 0.67. However, Table 5 shows that the actual ratios are not this low. A change from three to two lamps is most likely in a new installation. In a retrofit situation, it is more likely to

[1] See Berman et al., "Photopic Luminance Does Not Always Predict Perceived Room Brightness", LR&T 22(1), 1990; and Berman and Jewett, "Two-Dimensional Photometry for Interior Surround Lighting", JIES, 27(1), 1998.
[2] "Energy Efficiency Consequences of Scotopic Sensitivity", JIES 21(1), 1992.

keep the same number of poles, and reduce the wattage of the lamps while maintaining the same brightness. Table 6 shows the wattage reductions that are obtained in this case.

Table 5: Comparison of photopic and brightness lumen efficacy ratios at equal wattages

Watts		Efficacy ratios (HPS/MH)	
HPS	**MH**	**Photopic**	**Brightness**
35	#N/A		
50	50	1.64	1.03
70	70	1.51	0.96
100	100	1.45	0.92
150	150	1.37	0.87
200	200	1.18	0.75
250	250	1.35	0.85
310	300	1.32	0.84
400	400	1.28	0.81
600	#N/A		
750	750	2.12	1.34
1000	1000	1.76	1.11

Table 6: HPS and MH lamp wattages giving approximately equal brightness lumens

	Mean lumens			Mean lumens		
HPS watts	**Photopic**	**Brightness**	**MH watts**	**Photopic**	**Brightness**	**Watt ratio**
35	2025	1569				
50	3600	2789	50	2200	2694	1.00
70	5450	4222	70	3600	4409	1.00
100	8550	6623	100	5900	7226	1.00
150	14400	11154	150	10500	12860	1.00
200	19800	15337	175	14000	17146	0.88
250	27000	20914	200	16800	20576	0.80
310	33300	25794	250	20000	24495	0.81
400	45000	34857	350	29600	36252	0.88
600	81000	62742	750	46800	57318	1.25
750	99000	76685	1000	71500	87569	1.33
1000	126000	97599				

In general, efficacies increase with increasing wattages, so the savings in going to smaller lamps is less than the savings in going to fewer lamps. In the range of wattages most likely to apply to parking lots (70 – 400 watts), the Berman formula gives approximate savings of 15 percent for retrofits using reduced lamp count (Table 5), and 10 percent for reduced lamp wattage (Table 6). These are considerably smaller numbers than were estimated in the PIER report.

Additionally, it must still be determined whether the Berman formula is valid at parking lot lighting levels. The Berman experiment looked at photopic luminances in the range of 30 to 70 cd/m^2 in full field of view. Pavement reflectances are generally assumed to be about 7 percent, so these luminances are equivalent to illuminances of 1350 to 3100 lux, which is nearly 1000 times the illumination levels of parking lots. No validation exists for the Berman formula at pavement luminance levels. It is likely that the formula is actually conservative at these low light levels, as they are mesopic levels, where rod vision is expected to be important. This implies that the 10-15 percent savings values obtained above are likely to be conservative, but the degree to which they are conservative is difficult to determine. Brightness experiments by Sakawa and Ikeda were performed at mesopic levels; however, these studies unfortunately examined only a field of view of 10°. This would be appropriate for viewing the parking lot from outside, but not from within. Thus, these results may be no more applicable than the Berman work.

An even more critical question is whether lighting to equal brightness in a parking lot is appropriate. The IESNA lighting recommendations for parking lots (RP-20-98) state "It is intended that a driver (or pedestrian) looking at the brightest spot in the field of view will also be able to detect an object in the dark areas within the field of view." The lighting recommendations are intended to provide a minimum visibility, which is not the same as brightness. At low light levels, and in foveal (line of sight) view, it is the photopic luminance and the color rendering properties of the light source that determine visibility. Lighting only to equal brightness may not provide an appropriate level of visual performance in the foveal view. For off-axis viewing, however, the scotopic/photopic ratio again becomes important. A number of papers have been published on off-axis reaction times as a function of lamp spectra. Unfortunately, the results of these studies are not easily understood. In theory, the relative efficiency of a light source should shift smoothly from its photopic output at high light levels to its scotopic output at low light levels. However, papers by Lewis and Rea seem to indicate an inhibition of the scotopic channel by the photopic channel, so that visual performance at low light levels decreases more rapidly than would be expected from the S/P ratio (for less scotopically-rich sources). The problem is that even if this is true, performance in the central field remains dominated by the photopic luminance. Overall performance on a particular task may well be a mix of the central and peripheral views, and thus the scotopic and photopic luminances, but there is currently no agreed upon relationship.

Boyce has examined a number of performance measures for a parking lot under HPS and MH lighting[3]. He examined acuity, contrast sensitivity, visual search for a relatively achromatic object, off-axis detection (not reaction times), object identification, color naming, and a number of perceptual questions (comfort, feelings of safety, "good" lighting, glare, brightness, and appearance of people under the lighting). For all visual tasks except color naming, performance appeared to depend upon the photopic illuminance or luminance, and thus was better under an HPS lamp of the same wattage as the MH lamp. For color naming, which depends upon the illuminance level and color rendering properties of the light, HPS required ten times the light of MH to achieve equal accuracy (at high light levels, HPS lighting never achieves the accuracy of color naming found under MH lighting). However, it should be noted that even under the lowest HPS level, accuracy at color naming was only about 10 percent lower than that of the

[3] P. Boyce and L. Bruno, "An Evaluation of High Pressure Sodium and Metal Halide Light Sources for Parking Lot Lighting", JIES Vol. 28(2), pps 16 - 32, 1999.

equivalent wattage MH. In short, the Boyce study does not support the view that MH lighting will provide equal parking lot lighting performance at lower wattages than HPS.

Boyce's study is consistent with the limited survey information available from the PIER report, which indicates that subjects generally felt similarly about HPS and MH lamps in installed parking lot lighting. In the PIER study, subjects were asked whether parking lot lighting was: 1) comfortable, 2) provided good security, 3) made it possible to identify color, and 4) whether the lighting quality was worse, the same, or better than that of similar areas. Contingency table analysis indicates that there is a statistically significant difference in the response to these questions as a function of lamp type. An estimate of which differences are significant can be made by calculating the average probability of a positive response (1 equals yes and 0 equals no, or –1 equals worse, 0 equals same, and 1 equals better) and then calculating the differences in any two means over the estimate standard deviation of the response.

This type of analysis can be somewhat confusing because in any situation where more than two comparisons are being made there is the possibility that the groups of statistically similar cases are not distinct. For example, if a statistically significant difference is 1.2 units, and cases A, B, and C have values of 2, 1, and 0, then there is no statistically significant difference between A and B, or between B and C, but there is a significant difference between A and C. In table 7 below, lamp types which give statistically indistinguishable responses are shown in large bold type, and sequential lines show the different groups that can be formed in this manner. Thus, in answer to the question of whether a lot is comfortable, it was found that the responses for fluorescent through halogen lamps were statistically indistinguishable, and mercury through CFL were also indistinguishable. Mercury, LPS and halogen lamps are in both groups.

Table 7: Similarity groupings for Subjective Response Questions

Greater			**Comfort**				Least
FL	**HPS**	**MH**	**Hg**	**LPS**	**HAL**	INC	CFL
FL	HPS	MH	**Hg**	**LPS**	**HAL**	**INC**	**CFL**

Greater			**Security**				Least
FL	**HPS**	MH	Hg	LPS	HAL	CFL	INC
FL	**HPS**	**MH**	**Hg**	**LPS**	**HAL**	CFL	INC
FL	HPS	**MH**	**Hg**	**LPS**	**HAL**	**CFL**	INC
FL	HPS	MH	**Hg**	**LPS**	**HAL**	**CFL**	**INC**

Greater			**Color**				Least
CFL	**MH**	**FL**	**HAL**	**HPS**	**Hg**	**INC**	LPS

Greater			**Site comparison**				Least
MH	**HPS**	**FL**	**HAL**	**Hg**	**LPS**	CFL	INC
MH	HPS	FL	**HAL**	**Hg**	**LPS**	**CFL**	INC
MH	HPS	FL	HAL	Hg	**LPS**	**CFL**	**INC**

The responses in Table 7 are ordered with lamps at the left having the greatest probability of the desired response (comfortable, secure, etc). Both HPS and MH lamps score well, and in fact subjective responses to them were not significantly different. This is consistent with Boyce's finding that the white light from MH lamps did not provide a major advantage as compared to the yellowish light from HPS lamps. It is important to recognize that the comparisons in Table 7 represent comparisons against current practice. The comparisons are not controlled for differences in illuminances, or lighting distributions. This is probably the reason that incandescent lamps performed relatively poorly on the color identification question. Light level is very important in color recognition, so color recognition on a lot lit to a low level with incandescent lights will be no better and can even be worse than a lot lit to a higher level with HPS lamps[4].

Impact of standards on other lamp types

Fluorescent lamps (15.6 percent of reported lamps) have efficacies, which are comparable to equivalent wattage HPS lamps and have excellent color rendering. Their use is limited by their relatively low lumen outputs (and wattages), and for regular fluorescent lamps, their large size, with its added costs and difficulties in optical control. Fluorescent lamps are almost completely limited to canopy and low wattage wall lighting, where HID sources are often inappropriate. Since fluorescent lamps meet the efficacy limits proposed by the standard, have high color rendering, and provide good quality lighting (see Table 7 above), their use is unlikely to be affected by the draft standard.

Low pressure sodium lamps (3 percent of reported lamps) have no color rendering, but the highest efficacies of all lamps. They are also physically large in the higher wattages, and hence are hard to control optically. The issue of color is almost certainly the reason why the use of LPS is relatively uncommon, yet not zero. Although visibility is the primary purpose of lighting in a parking lot, color is an amenity, especially when attempting to distinguish one's car from a similar one parked nearby. Color recognition under LPS lighting is dependent on differences in reflectance, or from spill light from other nearby light sources. The survey results from the PIER study found that only 40 percent of the respondents felt able to recognize color in LPS lit lots, while the average in lots lit with other sources was over 80 percent. The data in Table 7 show that responses to LPS lamps are reasonably close to those for most other lamps, except for color. Color is presumably why LPS is not generally recommended for parking lighting. However, LPS is useful in vicinity of an observatory, or wherever there are a large number of amateur astronomers. The light is essentially monochromatic, which means that scattered light from LPS sources can be filtered out by the use of a "notch" filter, while almost all the rest of the visible spectrum passes through the filter, and is visible to the astronomer. LPS lighting meets the draft efficacy standards, and its use will be probably be unaffected by the standard.

[4] This data thus provides another indirect hint that savings from replacing incandescent lamps may be less than would be expected from efficacy alone, as it appears that such installations are substandard in performance and are likely to be upgraded if more efficient and expensive sources are being used.

Power and light levels
The state standards specify lighting maximum power levels. The IESNA recommendations specify minimum illuminance levels for reasonably safe movement of vehicular and pedestrian traffic, and the enhancement of personal security. Ideally, a lighting installation should be able to meet both the power density limitations imposed by the state, and the lighting safety levels recommended by the IESNA.

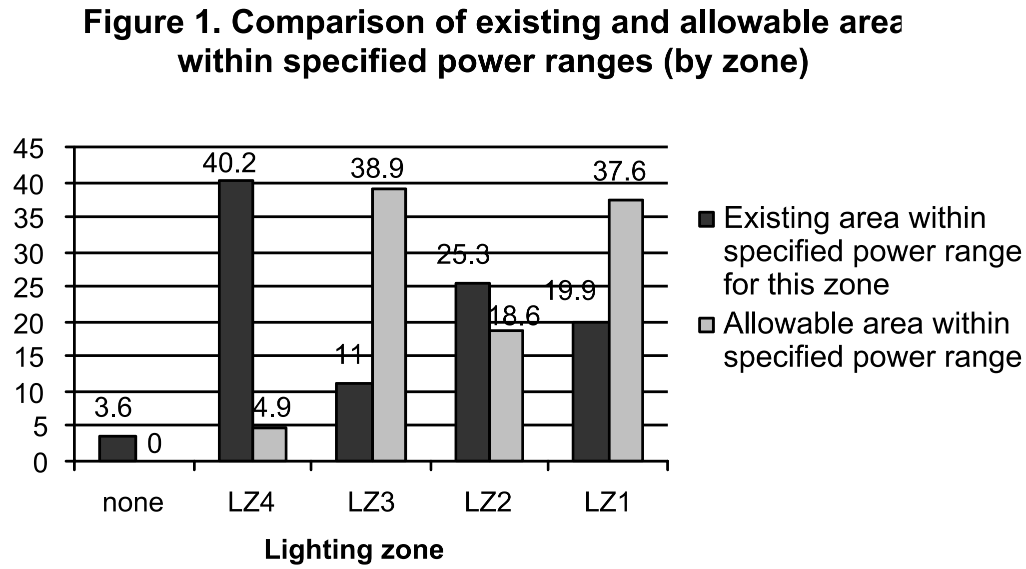
The Eley report proposes maximum power levels for each of the state's four environmental zones (see Table 8). The default zone designations are: LZ1 – Wildlife or Park; LZ2 – Rural; and LZ3 – Urban. Local governments can make adjustments to these designations, including an upgrade of LZ3 to LZ4 (High Illumination). At this time, the default zone designations are known, but the final geographical (legal) designation of the zones has not been determined.

Estimated potential energy savings from reduced power levels
The PIER report provides an estimate of the fraction of current parking lot lighting as a function of power density. In column 3 of Table 8 below, this data is used to calculate the fraction of parking lots, which meet the criteria for each of the zones (regardless of which zone the lots are actually in). Column 4 gives an estimate of the percentage of parking lot area, which are currently in each of the default zone classifications (irrespective of the actual power level used to light the lots). These values were estimated from several tables in the PIER report: table 9 (percentage of site area per zone for all exterior lighting), tables 60, 64, and 68 (percentage of sites per zone for all exterior lighting), and tables 34, 36, and 40 (percentage of sites per zone for parking lighting). From column 3 of Table 8, it can be seen that only 3.6 percent of existing lots exceed the power density requirements of the highest zone. In addition, 40 percent of the lots only meet LZ4 requirements. As LZ4 is not a default zone, no more than 10 percent of any city can be so designated. It seems unlikely that 40 percent of parking lot area is in the limited area that could be designated LZ4 (areas of high intensity night time use, such as adult entertainment districts). The average power density of this 40 percent of lots is approximately 0.11 watts/ft^2, so there is a potential for very significant energy savings if these lots are eventually modified to comply with the new code.

Table 8: Environmental zones: existing power density and area fractions

Zone	Watts/ ft^2	Existing	Default Zone Area
1	0.04	19.9%	37.6%
2	0.06	25.3%	18.6%
3	0.08	11.0%	38.9%
4	0.2	40.2%	4.9%
none	>0.2	3.6%	Not applicable

This information is presented graphically in Figure 1 below. The difference between the first and second columns for each zone represents the potential energy savings from reduced power levels. Note that in LZ3, LZ2, and LZ1, this is a negative value, which suggests that the greatest energy savings will result from power reductions above and within LZ4.



The potential energy savings can be estimated by calculating a power density from the fraction of areas in the default zones as given in column 4. For example, the 3.6 percent of the area that is over 0.2 watts/ft^2 is assumed to shift to zone 4 at 0.2 watts/ft^2. The 40.2 percent already meeting zone power levels is split with 1.3 percent remaining in zone 4 at the average power density for this zone (0.11 watts/ft^2) and the remaining 38.9 percent dropping to zone 3 at 0.08 watts/ft^2, and so on. The resultant estimated average power density is about 0.06 watts/ft^2, or about 25 percent less than current use. This is larger than the savings from changing lamps that have been described above (≈17 percent) , so some of the savings must come from a reduction in light levels. Note however, that the 25 percent savings potential is based on the default zone classifications. Changes in zone classifications by local governments could reduce or increase the actual level of savings.

Power requirements and illuminance criteria
According to the Eley report, the power density levels in LZ2 and LZ3 are based on the design criteria developed by the IESNA for parking lots for “basic” and “enhanced security” lighting, respectively: The PIER report provides a breakdown of parking lot lighting by these measures. Table 9 below lists the fraction of the parking lot area that appears to pass or fail the listed criteria. This table should be regarded as a preliminary estimate.

The measurements reported in the PIER report were made over a limited grid of points, and without further review it is not possible to determine how accurately the maximum and minimum points have been captured[5]. The Eley report describes a calculation procedure for each of the criteria based on the same grid size as the PIER report. The description in the report is essentially the center portion of a nine-pole grid (see footnote 5). Correspondence from Nancy Clanton and Larry Ayers confirms that only the central lit area was included in the calculation. The IESNA RP allows the use of a small area average in place of the actual minimum point where there is a problem with shadows, but it does not discuss actually excluding an area. Furthermore, the area in question is significant. In the example, calculations the area that is excluded from the calculations is large enough to accommodate one or two stalls and the access road in depth, and is over 55 percent of the lot area. The Eley and PIER values are almost certainly not consistent with the values one would obtain with the IESNA procedure.

Table 9: Fraction of area versus IESNA illuminance recommendation criteria

IESNA recommended practice for parking lots (RP-20-98)

	Minimum illuminance		
	Horizontal	**Vertical**	**Uniformity ratio**
Basic	2 lux	1 lux	20:1
Enhanced security	5 lux	2.5 lux	15:1

Criteria	**Horizontal**	**Vertical**	**Uniformity***
Does not meet minimum Basic criteria	40.5%	64.6%	31.3%
Does not meet minimum Enhanced criteria	29.5%	22.6%	15.6%
Exceeds both criteria	30.0%	12.8%	53.1%

* See text

The procedure used to develop the data for the PIER report was presumably the same as that used in the Eley report. This means that the minimum values will generally be overestimated, and the uniformity ratios will therefore be underestimated. Because the uniformity ratios are underestimated, the percentages listed above in Table 9 underestimate the true degree to which current lot design fails to meet recommended levels for uniformity. In table 9, uniformity was by far the least restrictive of the three

[5] The measurement procedure is given in the training manual for the measurements in the PIER report. The manual states that the "grid must cover 1/4 of the parking lot area," but then goes on to state that the surveyor is supposed to "measure between the poles and divide by 4". The surveyor is then supposed to put the first point at the pole base, and "measure from the pole base the calculated dimension and make a mark." This later description goes on to lay out a nine point grid that covers 1/4 of the area in a four-pole portion of a larger layout. The two instructions are not consistent. The more explicit later portion of the instructions does not describe which pole one starts from in a lot that has more than four poles. If it is a center location, then the grid is likely to get values near the maximum value, but it is not likely that the minimum will be correct. Similarly, if the grid is based on an edge grid, the minimum may be close, but the maximum will probably be underestimated. In either case, if poles are placed so that none sit on the perimeter of the lot, then the minimum is unlikely to be measured. Based on the descriptions given, it appears that the maximum and minimum listed should only be taken as rough guides to the true values for these parameters.

IESNA measures, with over 50 percent of existing lots supposedly meeting both the basic and enhanced criterion levels, as compared to only 12 percent meeting the vertical illumination level criteria. If, however, the measured uniformities were underestimated, the fraction of sites that actually fail to meet the IESNA uniformity recommendation may equal or even exceed the failure rates for horizontal or vertical illuminances.

The calculations in the Eley report were intended to show that the state power densities and IESNA illuminance criteria can be jointly met with MH lamps. The error in the calculation of the minimum illuminance value means that the examples may not actually meet the IESNA criteria, and therefore do not validate the standards. However, it must be noted that our review also uncovered what appears to be a second error that would tend to make the calculations conservative. The calculated power densities for the examples appears to be based just on the area within the rectangle defined by the 3 x 3 grid of poles, and did not include the lit area outside of this grid. The ratio of the area of the full lot to that of the inner grid is 2.25 to 1. The calculated wattage per pole can be computed from the pole spacing and the power density, and ranges from 2.22 to 2.25 times the input wattage of the lamps listed as being used on the poles. This means that the validation calculations could have been based on a smaller spacing to mounting height ratio, while still meeting the proposed power density standards. Smaller spacings give better uniformity ratios, so it is possible that revised calculations would meet the uniformity criteria. Actual validation that the IESNA recommended criteria can be met with the proposed power densities will require new calculations, but it at least seems plausible that both constraints can be met at the same time.

Although the standards proposed in the Eley report were not intended to set minimum illuminance requirements, it is reasonable to assume that adequate illumination should be maintained even when power densities are reduced. The analysis in Tables 8 and 9 indicates that there is a problem meeting both criteria in actual practice. For example, over 40 percent of parking lots meet zones 1 or 2 power density requirements (Table 8), but 40 to 60 percent also appear to fail the IESNA basic lighting criteria (Table 9). Also, over 50 percent of parking lots meet zones 3 or 4 power density requirements, and thus should meet IESNA's enhanced security lighting criteria. However, only 12.8 percent meet the vertical illuminance criteria, and only 30 percent meet the horizontal illuminance criteria. This indicates that it is either too difficult to meet both the power density and illuminance requirements, or there is a large potential to improve lighting design in the field. Based on current practice, it appears that a parking lot that meets the power density requirement is unlikely to meet the IESNA lighting requirements. This conclusion should be checked more carefully with the database.

To calculate lighting values for LZ1, the Eley report uses 50 percent of the IESNA criteria values for basic lighting (this is based on a footnote in the IESNA RP-20-98 document). The "basic" lighting criteria are intended to be safety criteria, but it appears that almost half of current parking lighting fails these criteria. If it is determined that increases in light levels (and thus lamp wattages) are necessary, this may result in a substantial increase in lighting energy requirements. Even if efficient sources are used, only 20 percent of existing sources are inefficient, which means that there will be a need to replace smaller lamps with larger lamps, which will increase energy use. However, if the layout is also changed, Eley's calculations suggest that LZ2 lighting can be made to meet both the safety criteria and the power density requirements. LZ1 lighting would still not meet the recommended illuminance criteria.

It should be noted that the validation calculations for lighting criteria as a function of power density appear to have been done for moderately large lots (108 to 240 stalls, or 32,000 to 72,000 square feet) with nearly square shapes (1 x 1 to 1.5 x 1 rectangles). This is the most efficient layout for lighting, but not all lots will have these shapes. Lots associated with buildings may have a longer aspect ratio, or may be L-shaped. Lots on hillsides may have curved or irregular perimeters. Such layouts are likely to make less efficient use of the luminaire's emitted light, and are therefore less likely to meet both the illuminance and power density requirements. The likely severity of these effects may best be determined from the PIER database, which has photos and layout information for the variety of parking lots studied.

Curfews

There is currently no restriction on lighting a parking lot for the entire evening. The Eley report recommends that there be a curfew time after which lighting is reduced or switched off. For LZ2 through LZ4, the draft standard requires a 50 percent reduction in power levels, and in LZ1, a 90 percent power reduction is required. There are several implications to these proposed curfew levels. The first is that reducing power to an HID by 50 percent may mean a 75 percent reduction in light output, and may make a major difference in color and color rendering. Current values for high/low ballast operation must be documented, as an installation in LZ3 which just meets the enhanced security lighting recommendations will fail the basic lighting criteria if light output drops by more than 60 percent. Light levels in LZ2 will almost certainly fall below this level. Reductions to 10 percent power levels, as are suggested for LZ1, may be difficult or impossible to meet with current technology for HID lamps, although they are possible with modern control systems for fluorescent lamps. Reductions of this magnitude may require a separate lighting system, if HIDs are providing the normal lighting. Also, minimum light levels at these power levels may be below 0.1 lux, and may not be sufficient to prevent transient blindness in pedestrians in the face of automobile headlights.

Glare, light pollution, and light trespass

Although not directly related to energy savings, issues of glare, light pollution, and trespass are also considered in the PIER and Eley reports. These issues do have an indirect effect on energy use in that tighter control of the light may mean slightly less efficiency. The Eley report states that parking lot lighting will require cut-off luminaires. Table 10 summarizes data from the PIER report on the fraction of luminaires by type that appear to be cut-off fixtures. Wall mount fixtures, as a class, appear to rarely meet this criteria, and thus may represent a significant opportunity for fixture development. Cut-off fixtures are often assumed to produce less light pollution (although this particular assumption has recently been questioned in a number of papers by Keith), light trespass and glare. The PIER report provides several tables that list glare and trespass data for existing sites, including glare ratios by building type, measurement location, and lighting zone, and trespass measurements by building type. For exterior lighting in general, it was noted that about 30 percent of sites produced more than 10 lux somewhere on the property line, and about 13 percent produced more than 20 lux at the property line. At present it does not appear possible to make any conclusions about the significance or implications of these results.

Table10: Fraction of luminaires by type and glare control

Fixture type	Percentage	Cut-off
Post top mount	44.6%	91.5%
Wall or landscape	22.9%	15.7%
Wall mount	14.6%	5.5%
Pole mount	10.7%	6.5%
Canopy	6.6%	37.9%
Undefined	0.4%	25.0%
Landscape	0.1%	100.0%

The PIER report gives instructions for taking the glare ratio measurement. The description of this procedure is not consistent between the written report and the training manual in the database. As the glare ratio is not a standard glare measurement, it is important to have some information on its actual relationship to perceptions of glare. Table 70 of the PIER report provides a comparison of the average glare ratio and average subjective impression of four different fixture types. Although the linear correlation coefficient, R, appears high (85 percent), it is not statistically significant for such a small sample. An analysis of the data in the database may produce a more robust and useful relationship, but at present it is not possible to analyze the PIER glare ratio data in a meaningful manner.

Table 70 does provide more detailed information about the subjective impressions of glare, and this makes it possible to do a statistical analysis comparing the different conditions studied. This analysis indicated a weak, but statistically significant preference for cut-off versus non cut-off fixtures, and for small fixtures (100 – <250 watts) versus larger fixtures (250 – 1000 watts). The subjective ratings range from 1 (best) to 5 (worst). None of the installations with the smaller fixtures received any votes of 5, and none of the small cut-off fixtures received even a vote of 4. This suggests that there may be benefits to cut-off fixtures outside of the issue of light pollution, and provides a firmer basis for their inclusion in the standard.

Other considerations

High mast lighting

There appears to be nothing in the current recommendations to limit the use of high mast lighting in zone 1, or any other zone. High mast lighting is probably not a good idea in locations where there is the possibility of very dense fog, as the increased scatter from the high mounting heights may make light penetration to ground level very poor. Lighter fogs may create light trespass issues, as the increased mounting heights will result in large amounts of light spill even if there is shielding. This may be particularly problematic for zone 1.

Illuminance caveat
In all the discussions above, it has been assumed that illuminance is the design goal. However, it is luminance, not illuminance that one actually sees. While parking lots use illuminance criteria as a design guideline, this is not current practice for roadways. On a roadway, the pavement provides the background for many of the critical tasks. The current North American roadway standard (RP-8) allows the designer to choose illuminance, luminance, or a particular visibility calculation. The later two alternatives are more recent, and are in a sense are preferred, but all three alternatives are still provided. In the parking lot, sight lines are shorter, and vehicles and pedestrians more common. Also, the pavement is not the background for many of the critical visual tasks. Horizontal and vertical illuminances are used as design criteria in the absence of targets and backgrounds of known reflectance. There are, nonetheless, efforts by some to replace the illuminance standards with luminance or visibility standards. If, or when, this happens, the criteria for optimal lighting design will also change. For example, if pavement luminance becomes a criteria, then pavement reflectance will become an important variable. At present it is nearly irrelevant, as it has almost no effect on illuminances in the field of view.

Conclusions

The following key points can be concluded from the above analysis:

- The energy savings from lamp replacements and efficacy improvements may not be as large as expected.

- It may be difficult to meet both the power density requirements and the illuminance criteria, if installations differ from the standard layout described in the Eley report.

- Curfew dimming may not be feasible due to the limitations of current technology and safety concerns.

Recommendations

Based on the above analysis, the following additional or alternative energy savings strategies are recommended:

1) Establish a set of optimal candlepower distributions for a range of layouts.
2) Use motion detectors instead of curfews.
3) Continue (at present) to allow use of both HPS and MH lamps.
4) Consider wall mount fixtures as a potential target for retrofit efforts.

These strategies are discussed further in the following paragraphs.

Optimal lighting system design

The CEC draft standard limits the wattage/ft^2 for parking lots as a function of the lighting zone, which is effectively a restriction on the average light levels of the parking lot for each of the four zones. The IESNA recommendations limit minimum horizontal and vertical illuminance levels. This implies that the most efficient lighting is that which has the best uniformity, while still meeting vertical illuminance requirements. This is a system issue. For any particular parking lot geometry, and fixture placement, there will be an optimal candlepower distribution. Manufacturers cannot make different distributions for each and every possibility, so the issue comes down to defining the most common layouts, and the candlepower distributions that work best over a range of conditions for these layouts. The Eley report did calculations for one standard type of layout, which consisted of fixtures on a regular grid on the interior of the parking lot. Two other layouts that are likely to be common are perimeter-mounted systems, and single sided wall mount systems. The requirements for the systems are clearly different. For instance, an almost triangular illuminance distribution from a single luminaire could give excellent uniformity on a parking lot if it overlaps with other triangular distributions from neighboring fixtures, but will give terrible uniformity if it is used for single-sided lighting from a wall.

Figures 2 – 4 illustrate this issue with respect to combining two pole-mounted fixtures. Figure 2 shows the light distribution for a standard fixture as a function of the distance perpendicular to the light. As can be seen from the figure, there is a triangular portion to the distribution. In Figure 3, a second fixture is placed 0.75 mounting heights away, which puts it right at the peak of the triangle. The uniformity over this space, and along this line, is phenomenal. Figure 4 shows what happens when the spacing to mounting height is increased to 2. The uniformity, at least on the line between the fixtures, has declined significantly. It seems likely, especially given the results in Tables 8 and 9, that work on this issue could result in substantial improvements in uniformity and average power density levels.

Figure 2: Illuminance distribution from single fixture in a direction perpendicular to the fixture mounting.

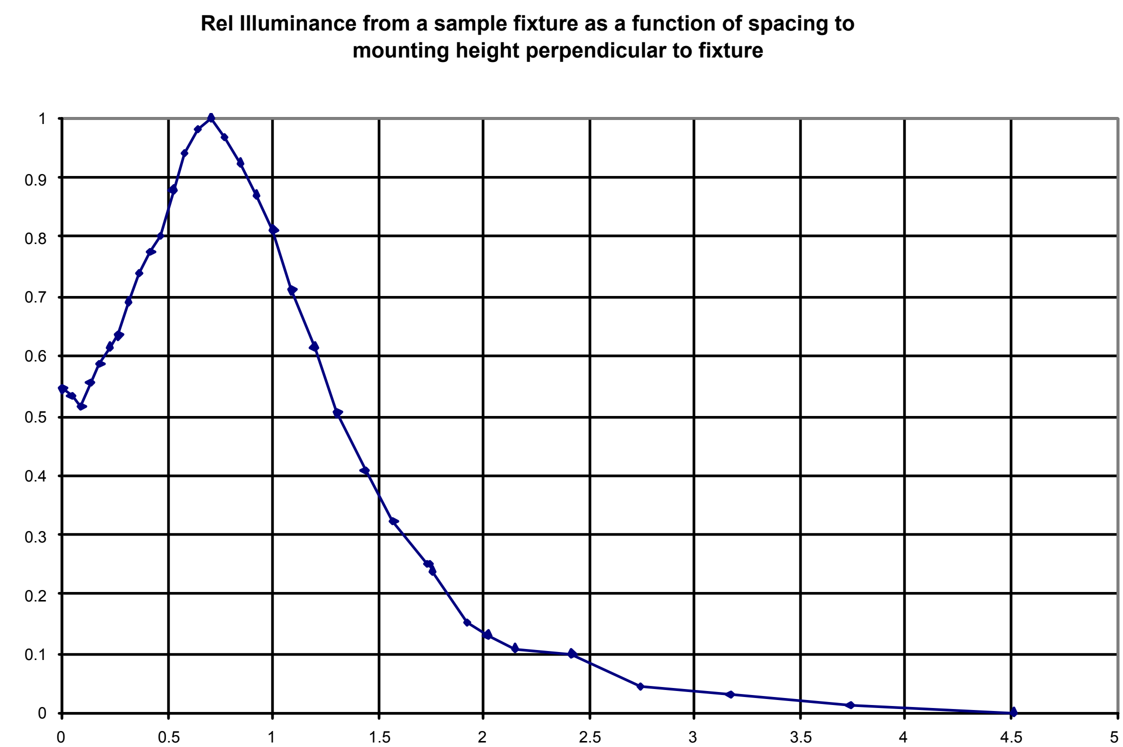


Figure 3: Illuminance distribution on line between two fixtures, both with the same candlepower distribution as the fixture in figure 2. The spacing to mounting height ratio is 0.75.

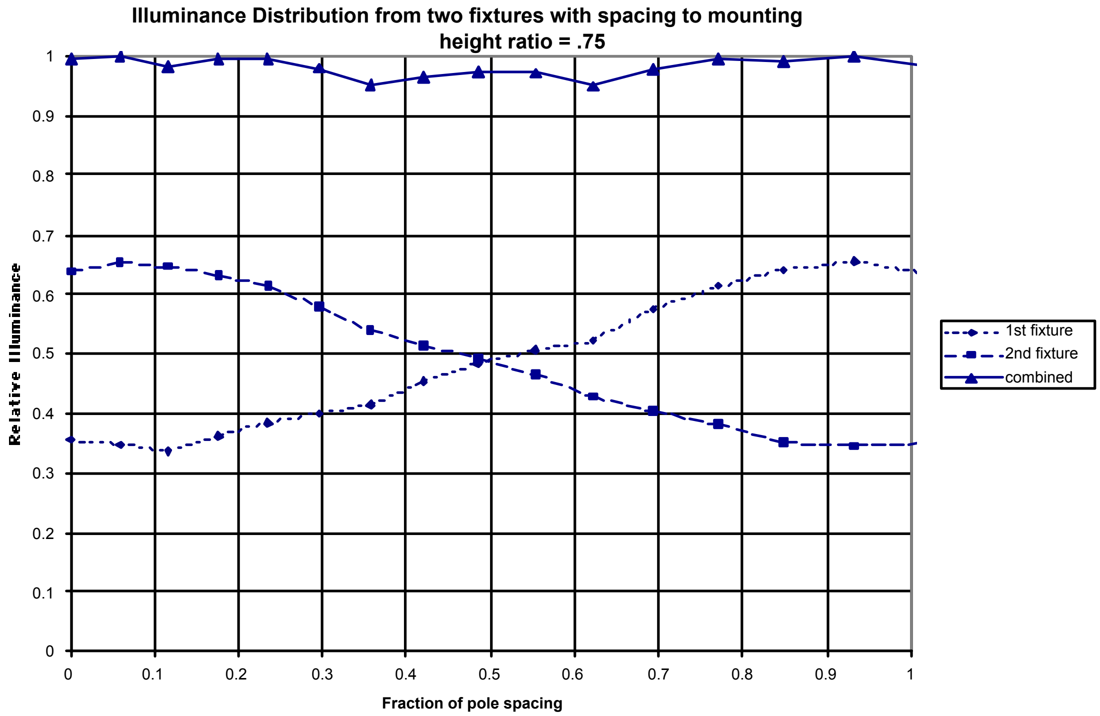


Figure 4: As in figure 3, but with a spacing to mounting height ratio of 2.

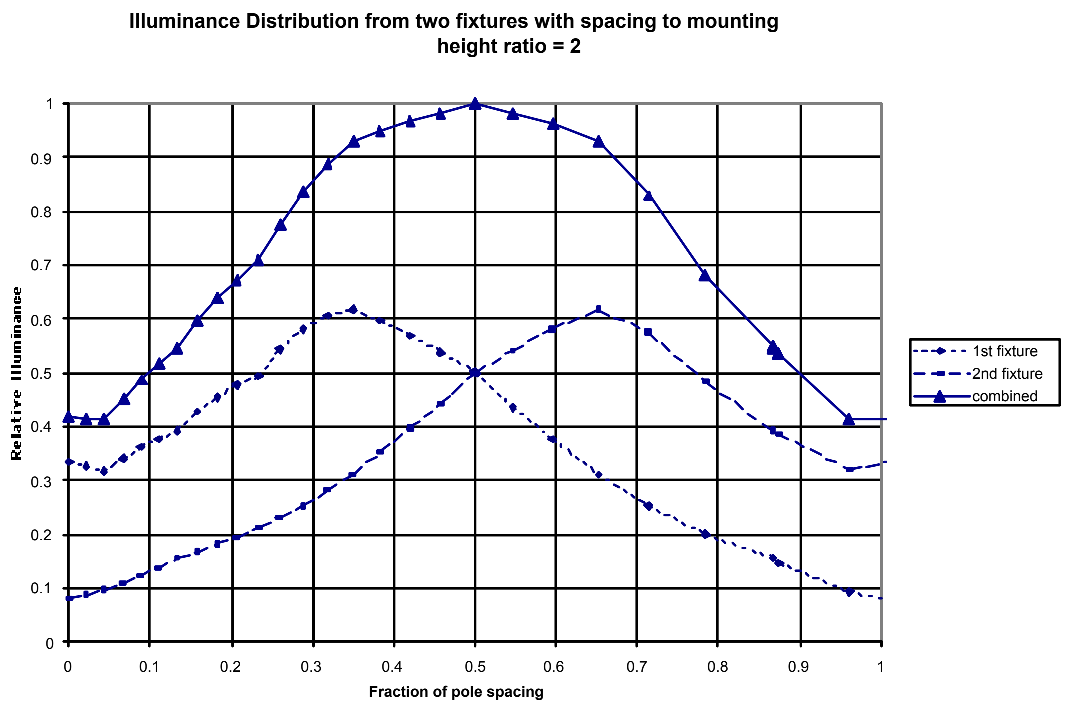
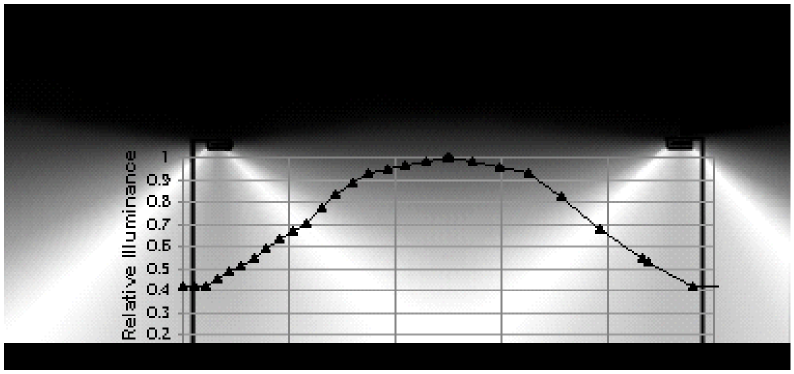
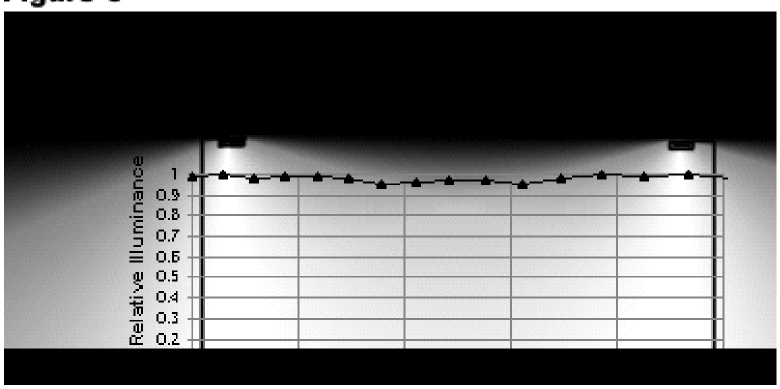


Figure 5



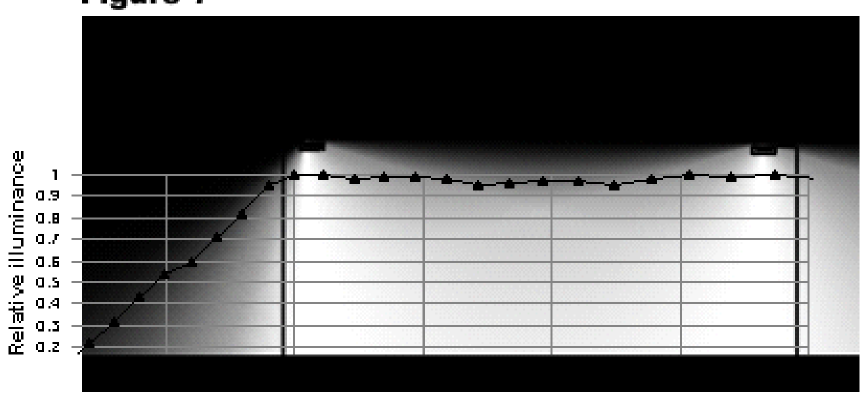
poor illuminance uniformity

Figure 6



good illuminance uniformity (interior fixture)

Figure 7



good illuminance uniformity (edge fixture)

An example using wall-mounted fixtures provides an even more extreme demonstration of the potential for saving energy by changing candlepower distributions. Computer calculations were run for the illuminance distributions from several wall mount fixtures. Table 11 shows the relative illuminance values as a function of distance along and from the wall. Figure 8 illustrates this information conceptually in three dimensions.

Table 11: Relative illuminance levels on parking lot lit with wall mount fixtures

Relative illuminance levels on parking lot lit with wall mount fixtures
Lot boundary shown as a border
Distance along wall divided by mounting height)

Distance away from wall	-0.5	-0.25	0	0.25	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4	4.25	4.5
							Fixture								**Fixture**						
0	0.01	0.03	0.13	0.32	0.56	0.78	0.68	0.78	0.58	0.35	0.25	0.35	0.58	0.78	0.68	0.78	0.56	0.32	0.13	0.03	0.01
0.1	0.03	0.09	0.24	0.43	0.67	0.85	0.77	0.86	0.70	0.52	0.48	0.52	0.70	0.86	0.77	0.85	0.67	0.43	0.24	0.09	0.03
0.2	0.07	0.16	0.33	0.50	0.73	0.87	0.82	0.89	0.80	0.67	0.66	0.67	0.80	0.89	0.82	0.87	0.73	0.50	0.33	0.16	0.07
0.3	0.11	0.24	0.38	0.56	0.75	0.85	0.81	0.88	0.85	0.79	0.76	0.79	0.85	0.88	0.81	0.85	0.75	0.56	0.38	0.24	0.11
0.4	0.16	0.30	0.44	0.61	0.76	0.79	0.77	0.84	0.90	0.91	0.87	0.91	0.90	0.84	0.77	0.79	0.76	0.61	0.44	0.30	0.16
0.5	0.22	0.34	0.49	0.65	0.73	0.71	0.70	0.80	0.93	0.99	0.98	0.99	0.93	0.80	0.70	0.71	0.73	0.65	0.49	0.34	0.22
0.6	0.25	0.36	0.51	0.64	0.65	0.64	0.64	0.74	0.88	0.99	1.00	0.99	0.88	0.74	0.64	0.64	0.65	0.64	0.51	0.36	0.25
0.7	0.25	0.36	0.49	0.57	0.56	0.56	0.58	0.67	0.79	0.92	0.95	0.92	0.79	0.67	0.58	0.56	0.56	0.57	0.49	0.36	0.25
0.8	0.25	0.37	0.45	0.50	0.49	0.50	0.52	0.61	0.71	0.85	0.88	0.85	0.71	0.61	0.52	0.50	0.49	0.50	0.45	0.37	0.25
0.9	0.24	0.34	0.41	0.43	0.43	0.45	0.48	0.55	0.64	0.75	0.79	0.75	0.64	0.55	0.48	0.45	0.43	0.43	0.41	0.34	0.24
1	0.24	0.31	0.36	0.38	0.38	0.40	0.43	0.49	0.58	0.65	0.70	0.65	0.58	0.49	0.43	0.40	0.38	0.38	0.36	0.31	0.24
1.1	0.23	0.28	0.32	0.33	0.34	0.36	0.39	0.44	0.52	0.57	0.61	0.57	0.52	0.44	0.39	0.36	0.34	0.33	0.32	0.28	0.23
1.2	0.22	0.26	0.29	0.29	0.31	0.33	0.36	0.41	0.47	0.50	0.54	0.50	0.47	0.41	0.36	0.33	0.31	0.29	0.29	0.26	0.22
1.3	0.20	0.24	0.26	0.26	0.28	0.30	0.33	0.38	0.42	0.45	0.47	0.45	0.42	0.38	0.33	0.30	0.28	0.26	0.26	0.24	0.20
1.4	0.19	0.22	0.23	0.24	0.26	0.28	0.30	0.35	0.38	0.40	0.42	0.40	0.38	0.35	0.30	0.28	0.26	0.24	0.23	0.22	0.19
1.5	0.18	0.20	0.21	0.22	0.24	0.26	0.28	0.32	0.35	0.37	0.38	0.37	0.35	0.32	0.28	0.26	0.24	0.22	0.21	0.20	0.18
1.6	0.16	0.19	0.19	0.20	0.22	0.24	0.26	0.30	0.32	0.34	0.34	0.34	0.32	0.30	0.26	0.24	0.22	0.20	0.19	0.19	0.16
1.7	0.15	0.17	0.18	0.19	0.21	0.22	0.25	0.27	0.30	0.31	0.30	0.31	0.30	0.27	0.25	0.22	0.21	0.19	0.18	0.17	0.15
1.8	0.14	0.16	0.16	0.18	0.20	0.21	0.23	0.25	0.27	0.28	0.27	0.28	0.27	0.25	0.23	0.21	0.20	0.18	0.16	0.16	0.14
1.9	0.14	0.15	0.15	0.17	0.18	0.20	0.21	0.23	0.25	0.26	0.25	0.26	0.25	0.23	0.21	0.20	0.18	0.17	0.15	0.15	0.14
2	0.13	0.13	0.14	0.16	0.17	0.19	0.19	0.21	0.23	0.24	0.23	0.24	0.23	0.21	0.19	0.19	0.17	0.16	0.14	0.13	0.13
2.1	0.12	0.12	0.13	0.15	0.16	0.17	0.18	0.20	0.21	0.22	0.21	0.22	0.21	0.20	0.18	0.17	0.16	0.15	0.13	0.12	0.12
2.2	0.11	0.12	0.13	0.14	0.16	0.16	0.17	0.18	0.20	0.20	0.20	0.20	0.20	0.18	0.17	0.16	0.16	0.14	0.13	0.12	0.11
2.3	0.10	0.11	0.12	0.13	0.15	0.15	0.15	0.17	0.18	0.18	0.18	0.18	0.18	0.17	0.15	0.15	0.15	0.13	0.12	0.11	0.10
2.4	0.09	0.10	0.11	0.13	0.14	0.14	0.14	0.15	0.16	0.17	0.17	0.17	0.16	0.15	0.14	0.14	0.14	0.13	0.11	0.10	0.09
2.5	0.09	0.10	0.11	0.12	0.13	0.13	0.13	0.14	0.15	0.16	0.16	0.16	0.15	0.14	0.13	0.13	0.13	0.12	0.11	0.10	0.09
2.6	0.08	0.09	0.10	0.12	0.12	0.12	0.12	0.13	0.14	0.14	0.15	0.14	0.14	0.13	0.12	0.12	0.12	0.12	0.10	0.09	0.08
2.7	0.08	0.08	0.10	0.11	0.11	0.11	0.11	0.12	0.13	0.13	0.13	0.13	0.13	0.12	0.11	0.11	0.11	0.11	0.10	0.08	0.08
2.8	0.07	0.08	0.09	0.10	0.10	0.10	0.10	0.11	0.11	0.12	0.12	0.12	0.11	0.11	0.10	0.10	0.10	0.10	0.09	0.08	0.07
2.9	0.07	0.07	0.08	0.09	0.09	0.09	0.09	0.10	0.10	0.11	0.11	0.11	0.10	0.10	0.09	0.09	0.09	0.09	0.08	0.07	0.07
3	0.06	0.07	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.10	0.10	0.10	0.09	0.09	0.08	0.08	0.08	0.08	0.08	0.07	0.06
3.2	0.05	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.05
3.4	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.05
3.6	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04
3.8	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04
4	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03

Figure 8: Conceptual Illustration of Candlepower Distribution versus Illuminance for Two Wall Mount Luminaires.

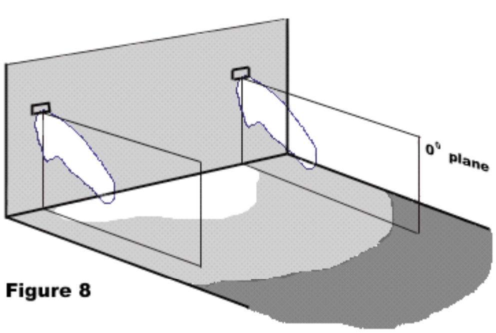


Figure 8

The uniformity ratio for this installation just meets the 20:1 criteria, and the minimum illuminance is over 2 lux. The luminaire efficiency (lumens out of fixture/lumens out of lamp) of this fixture is only about 57 percent, but its utilization efficiency (lumens on task/lumens out of fixture) is very high (84 percent), so the coefficient of utilization (lumens on task/lumens out of lamp) is reasonable (47.5 percent). But this is only part of the story. Because the installation just meets the uniformity criteria, the specification efficiency (lumens on the task area/lumens required by the specification) is low (14 percent). Although it is not part of the IESNA specification, this last calculation included a border area at about half the minimum required for the lot itself. A strict interpretation of the specification gives an even lower efficiency. The overall application efficiency (lumens required by the specification/lumens out of lamp) is the product of the coefficient of utilization and the specification efficiency, and is 6.7 percent. The efficiency values indicate that there may be substantial room for improvement, especially in modifying the candlepower distribution, despite the fact that this installation has a power density close to 0.04 watts/ft^2 (note that compliance with the vertical illuminance requirements has not been checked in this example). Specification efficiencies for the parking lot specification do not appear to have been examined in the past, so there is no information on how close to 100 percent that a design can get. Still, it seems likely that the potential is significantly greater than 7 percent, indicating a possibility of significant future energy savings in this area.

Motion detector-controlled fixtures

Curfews save energy by reducing lighting when demand for it is low. However, it might be argued that it is not that demand is low during potential curfew periods, but that the potential for demand is low. A potential problem with a simple curfew is that the light levels may be reduced below recommended safety levels. The use of a motion detection fixture with a bi-step output could avoid this problem, while still potentially reaping much of the benefits of reduced curfew levels. A motion detector could turn on the light to provide full service whenever there was activity, and dim or turn off the light when no motion was detected. Simple on-off switching motion detectors are common for incandescent lights, but not other lights. Bi-level switching is less common, but has been developed for use in stairwells with fluorescent lights. Development of this technique for HID lighting could extend the application to parking lots.

Retrofit fixtures

Calculations in the Eley report of the lighting levels as a function of power density were based on a pole or post mounted symmetric distribution fixture. The PIER report lists information on the fixture types actually found, as well as providing drawing from which one can judge whether the fixture is a full cut-off type. Table 10 above summarizes this information by mounting and cut-off type. The fixture type percentages are surprisingly not equivalent to standard roadway practice (almost all pole mount). The large fraction of canopy-mounted fluorescent fixtures is particularly surprising. The category “wall or landscape” indicates that the fixture could be mounted in either location, however for parking lot lighting, the actual location will probably be on the wall. This means that wall mount fixtures are over 1/3 of the current installed parking lot lighting. Most wall mount, and most standard pole mount fixtures, are not cut-off fixtures, while most post-top fixtures are. It seems likely that the greatest potential for glare reduction is for wall mount fixtures. The single biggest sector is the post-top fixture, but the retrofit and new installation issues here appear as if they will need to be more focused on efficiency issues.